Modelling field operations in a computable general equilibrium model: An application to labour shortages in Bhutan

1. Introduction

The majority of labour force in the developing world is employed in the agricultural sector (World Bank, 2017), where due to the lack of machinery and modern inputs such as mineral fertilizer and chemical plant protection, agriculture is characterized by labour intensive farming systems. In countries like India agricultural productivity was increased through the adoption of modern technologies during the course of the green revolution, which allowed the release of labour to non-farm sectors boosting economic growth. In many other countries, the potential of modern inputs is still underdeveloped and various efforts are made to increase agricultural productivity predominantly by reducing labour intensity. As agriculture is a complex production system, there are various technological trade-offs which can be targeted by policy. Often interventions aim at one specific production stage within agriculture. Fertilizer subsidies, for example, may decrease the labour intensive application of manure, but will not affect most other field operations such as land preparation, weeding and irrigation.

Generally, computable general equilibrium (CGE) models have been proven useful to ex-ante analyse the economy-wide effects of policy measures. However, CGE models often incorporate a rather simplistic production structure, which might lead to inaccurate estimates of effects induced by such specific inventions in the agricultural sector as specified above. This paper makes a novel methodological contribution by developing a CGE model with a production structure that separates the agricultural production system into distinct field operations. Doing so allows the modeller to directly identify and shock technological trade-offs in the various production stages of agriculture.

Bhutan is chosen as a case study, where agriculture employs more than 50% of labour force (NSB and ADB, 2012). Cropping systems in Bhutan are characterized by high labour intensity. Various efforts by the government have focused on increasing agricultural productivity through, for instance, subsidizing farm mechanization. At the same time, with increasing rural-urban migration, rural labour shortages are becoming an urgent challenge to farmers in Bhutan. In a 2014 survey, 48% of farmers mentioned labour shortages as a farming constraint (MoAF, 2015).

We develop two model setups to simulate a scenario of a 5% reduction in Bhutan's rural labour force. Model setup 1 mimics the production structure of CGE models that were previously applied within the context of agriculture. Model setup 2 is an extended version that explicitly incorporates field operations. These field operations contain additional information on the technological trade-off between traditional, labour intensive field operations with more labour efficient field operations that rely on modern inputs and technology. By contrasting the model results we will investigate to what extent incorporating field operations provides additional insights from both a modelling and policy perspective.

The paper is structured as follows: Section two reviews the literature on modelling production in a CGE-framework, whereby a special focus is put on the agricultural sector. The database applied to this analysis is presented in section three. The methodology is described in section four, outlining the model setups and the implementation of the rural labour reduction scenario. Section five contains the simulation- results, which are discussed in section six.

2. Literature review

Generally in CGE models the production structure of activities is described as a "technology tree", consisting of a series of nested constant elasticity of substitution (CES) production functions or fixed share aggregates (Leontief assumption). The underlying assumptions are constant returns to scale and separability, meaning that the marginal rate of substitution between inputs aggregated in one nest is independent of the quantity of any other inputs used.

Most standard/basic models apply a simple two to three stage nesting, in which on the top-level aggregate intermediate inputs are combined with total value added. On the level below, on one side value added is composed of production factors, usually labour, capital and for agricultural activities: land. On the other side, commodities are aggregated to form intermediate input. These commodities are produced domestically or are imported from the rest of the world. This is reflected either by an additional nest forming composite commodities (of imports and domestic production) such as in the IFPRI standard model (Lofgren *et al.*, 2002) or imports and domestic commodities are aggregated on one level as in the Global Trade Analysis Project (GTAP) model described in Hertel (1997). In the latter model, the source of imports is specified by an additional nest.

There is no general consensus on the choice of CES or Leontief production technologies for production nests to assume CES or Leontief technology. However, most models assume (imperfect) substitution between single factors as well as between imported and domestically produced inputs (Armington assumption (1969)) (e.g. the GTAP model, (Hertel, 1997), while intermediate inputs are often aggregated in fixed shares, assuming no adaptation towards a relative price change of commodities (e.g. STAGE 2 as documented in McDonald and Thierfelder, 2015). This means for example, a farmer always needs to purchase a similar quantity of seeds in order to produce a certain quantity of crop, i.e. seeds cannot be substituted by other inputs.

This simple production structure has the advantage that it is widely applicable as it requires a limited amount of data for parameterisation. However, it can be criticized for oversimplification and crude assumptions, which might lead to unrealistic results, especially regarding effects on the micro-level. Therefore, authors have expanded this production structure by adding further nests for example to distinguish labour categories of different degree of substitutability (e.g. STAGE_LAB as described in McDonald and Thierfelder (2009)) or different sources of energy (e.g. GTAP-E as described in Burniaux and Truong (2002) or the adjusted ORANI-G model as described by Meng (2015)).

Quite some research has been focused on the production structure in the agricultural sector especially as it is it is of special relevance regarding the use of land and water resources and contributes to a large share of GDP, employment and livelihood in many countries. Also, as pointed out above, manifold specific technological trade-offs make the agricultural production system quite complex. Studies with a focus on the agricultural sector have moved commodities such as fertilizer and agro-chemicals to the value added side in order to allow for an adjustment of production intensity (e.g. Argüello and Valderrama-Gonzalez, 2015). The same has been done for oxen ploughing services, being a coupled product to livestock production (Holden et al., 2005).

As on average agriculture accounts for about 70% of global water consumption, many studies introduce water from different sources and in different ways as an additional production factor (see Dinar, 2014 for a review). Taheripour et al. (2013) go beyond what had been done before in this respect, by introducing a sub-national dimension on a global scale, limiting water movement to within riverbeds only. Osman et al. (2016) include a sub-annual time dimension in a single country model, by introducing seasonal cropping activities and season-specific water supply.

A very detailed agricultural production structure has been integrated in a village-level CGE by Kuiper (2005). The model features individually calibrated CES-nests for agricultural activities and allows for example for (imperfect) substitution between chemical and organic fertilizer (manure), animal and tractor ploughing as well as between labour and chemical plant protection. A similar approach is followed in this study, which goes beyond the village level applying the developed model on a country scale. Thereby, unlike the previous approaches, the model presented here considers different specific field operations, which allow for a more precise distinction of substitutability e.g. chemical plant protection might be a good substitute for labour intensive hand weeding but cannot substitute labour employed in harvesting.

3. Model database

The model's underlying database is a 2012 Social Accounting Matrix (SAM) for Bhutan wherein the structure of economic institutions and agents is determined (Feuerbacher *et al.*, 2017). The 2012 SAM was extended by disaggregating the agricultural sector according to conventional and organic activities. In total, the SAM consists of 153 accounts. 63 commodities are produced; thereof 41 are either outputs or inputs of agricultural production. There are 55 activities, of which 39 are directly related to agriculture. The SAM has 14 factor accounts, of which 10 are demanded by agriculture. Agricultural labour is disaggregated into own farm labour (*faglab*) and hired labour from landless households (*fagwage*). Non-agricultural labour is disaggregated into skilled and unskilled labour. Agricultural capital consists of machinery and is subdivided into two categories: powertillers (*ftiller*) and other machinery, which is aggregated into informal capital (*finfcap*). Livestock is disaggregated into a cattle and other animal capital account (*fcattle* and *fothanimals*). Capital of incorporated enterprises consists of private and public capital. Returns of the latter represents income to the government from state owned enterprises. Land is disaggregated into irrigated land used for rice production (*fwetland*), rainfed land (*fdryland*) and land used for perennial crops (*forchard*). The SAM further includes 8 household accounts, which are disaggregated according to factor ownership and residence in either rural or urban areas.

3.1. Incorporation of field operations in model database

In model setup 2, we modify the SAM as follows. We utilize farm budget data to disaggregate inputs and production factors according to 13 major field operations. Each field operation is an activity producing a corresponding field operation commodity that enters the crop producing activity as a production input. Table 1 gives an overview on the field operations represented in the model:

Table 1 - Description of field operations

Activity	Description	Inputs	Output
anursery	Nursery operations	Labour	cnurse
amechlp	Land preparation using powertillers	Labour, diesel powertiller (ftiller)	cmechlp
adraughtlp	Land preparation using draught animals	Labour, draught animal services	cdraughtlp
amanlp	Manual land preparation	Labour	cmanlp
asowplant	Sowing and planting (incl. transplanting)	Labour	csowplant
aorgfert	Organic fertilizer application	Labour, manure	corgfert
achemfert	Chemical fertilizer application	Labour, chemical fertilizer	cchemfert
aothop	Other operations incl. staking, fencing, pruning	Labour, other agricultural machinery (finfcap)	cothop
airrig	Irrigation	Labour	cirrig
aorgprotect	Organic plant protection by only manual weeding	Labour	corgprotect
achemprotect	Chemical plant protection by weeding and pesticide application	Labour, chemical pesticides	cchemprotect
acropguard	Crop guarding of plots against wild animals	Labour	ccropguard
aharvest	Harvesting	Labour	charvest

The explicit incorporation of field operations is a novel feature. While the SAM already contained the information on the various inputs (e.g. manure, chemical fertilizer), explicit modelling of field operation allows to include additional information how much labour (including both agricultural farm labour and hired labour) is involved to apply these inputs. For example, organic plant protection is known to require much more person-days per hectare compared to chemical plant protection. The same holds for the application of organic fertilizer vis-à-vis chemical fertilizer. The technological trade-off can result in significant differences in labour intensity. A recent study interviewing 726 paddy farmers in Bhutan has found organic farmers to have an 11% higher total labour requirement compared to conventional farmers, due to manual weeding and application of manure (Tashi and Wangchuk, 2016).

The input-output structure of each field operation is not specific to the crop activities. Instead, due to data paucity we assume that technological trade-offs within field operations are identical across crops. In other words, each unit of chemical protection contains the same ratio of labour and pesticides whether demanded by paddy or potato producing activity. However, available data on the input levels per crop was used to derive crop-specific input structures of the various field operations.

4. Methodology

4.1. Model framework

The CGE model adapted for this study is the single country, comparative-static STAGE 2 model which is comprehensively described in McDonald and Thierfelder (2015). Both linear and non-linear relationships govern agents' behaviour towards changes in model parameters and variables. The agents in the model are production activities, households, incorporated enterprises, the government and the capital market. Household consumption follows the Linear Expenditure System derived from Stone-Geary utility functions assuming utility-maximizing behaviour. This entails differentiation between subsistence and discretionary consumption. Following the Armington insight (1969), demand for domestically produced and imported commodities is imperfect and specified by a Constant Elasticity of Substitution (CES) function. Domestically produced commodities are supplied to the domestic and world market (i.e. exports) using Constant Elasticity of Transformation (CET) functions.

The original production structure in STAGE2 is a three-level nested production process. Each nest forms a production input aggregate according to either Leontief or CES technologies. Leontief aggregates are determined in fix shares. The CES technology allows for flexibility in aggregation of inputs according to their relative prices.

4.2. Model setup 1

The first model setup that we use to simulate the reduction in rural labour force is in the spirit of agricultural production structures that are commonly applied in literature (also refer to the literature review). Generally, we assume that intermediate inputs and value added components are aggregated according to Leontief technology (level L1 in Figure 1). Intermediate inputs are also demanded in fixed shares (L2.1). Intermediate inputs include all commodities, except chemical fertilizer (cfert) and manure (cmanure), which are integrated on the value added side. At the value added nest (L2.2), factor classes (labour, capital and fertilised land) are aggregated to form total value added. All capital (including powertillers) and labour are aggregated within the respective nests at L3.2 and L3.3. For cropping activities the area cultivated and fertilizers are aggregated using CES technology at L3.1. Only cropping activities use land so that L3.1 is empty for all other activities. The nest at L4.1 aggregates the various land types (fwetland, fdryland, forchard) in case a crop is cultivated on multiple land types. The fertilizer aggregate at L4.2 consists of only fertilizer commodities, whereas in model setup 2 it will consist also of the corresponding labour needed to apply the fertilizer.

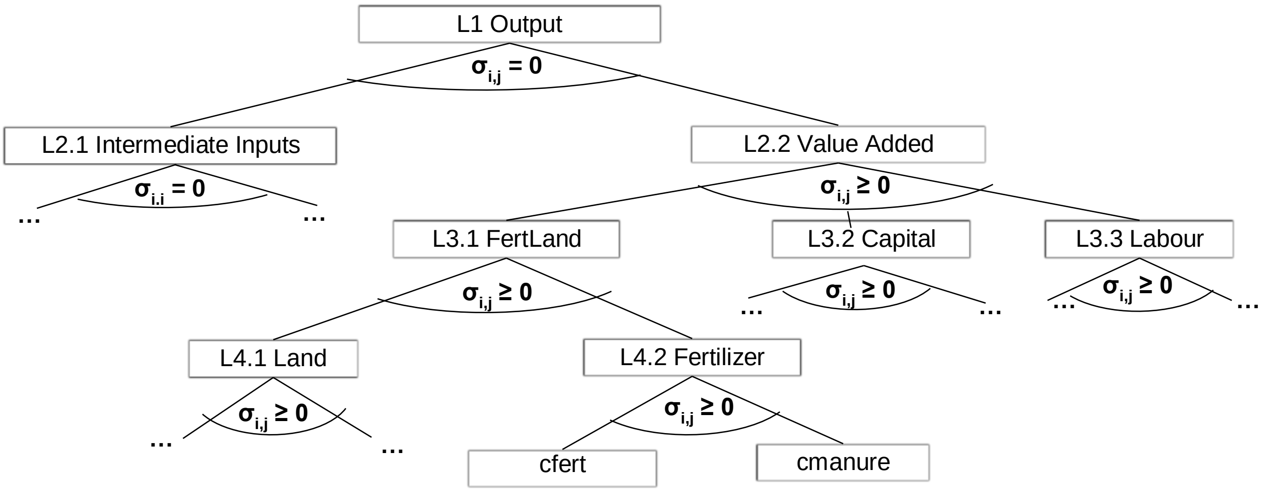

Figure 1 - Production structure of model setup 1

4.3. Model setup 2

Model setup 2 involves a significant extension of the production structure in order to integrate field operations as illustrated in Figure 2. The differences to model setup 1 begin from L3.1. Similar to model setup 2, the nest at L3.1 governs the activities' degree of intensification. However, the fertilizer aggregate at L4.2 now consists of the field operations of organic and chemical fertilizer application (corgfert and cchemfert). Doing so allows to depict the higher labour requirement needed for the application of organic fertilizer. Instead of directly aggregating land with the fertilizer aggregate, another nest referred as AreaCultivated is included at L4.1. This nest aggregates land and all remaining field operations according to Leontief technology. Assuming a fixed share between field operations and land is reasonable, as increasing the area cultivated would in reality also leads to a higher requirement of labour, which is included in the field operations. The remaining field operations are aggregated in the nests at L5 and L6. Besides land preparation and plant protection, all remaining field operations are directly aggregated at level 5. At level 6.1, three different land preparation technologies aggregated. Organic and conventional plant protection practices are aggregated as the plant protection aggregate in L6.2

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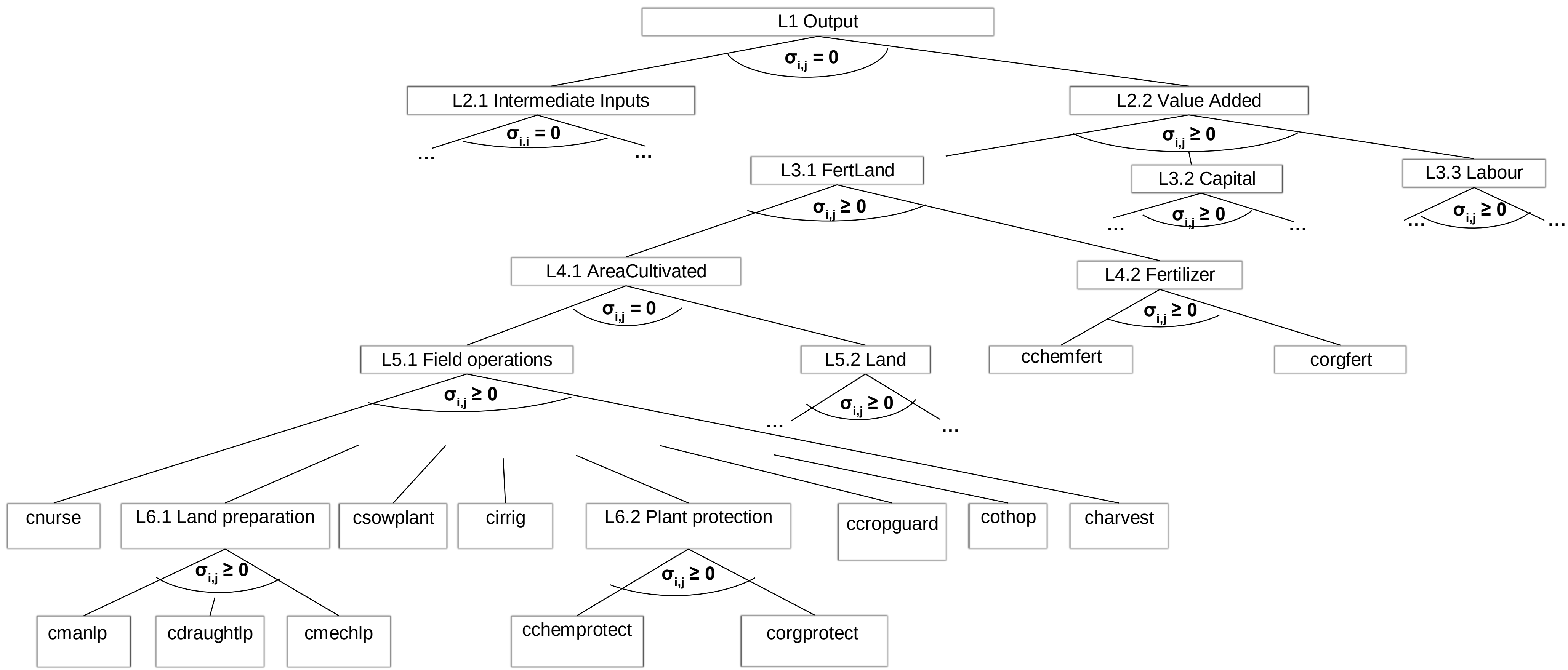

Figure 2 - Production structure of model setup 2 – incorporation of field operations

4.4. Further model extensions

In addition, the following three extensions to the original STAGE 2 model framework are implemented to both model setups 1 and 2. Firstly, while STAGE 2 already includes trade and transport margins for domestic consumption, both setups also incorporate margins for exports, as due to the mountainous terrain in Bhutan considerable transport costs apply to export-goods as well. Secondly, more flexibility regarding the output of selected multi-product activities (i.e. the livestock and forest activities) is allowed for by introducing constant elasticity of transformation (CET) functions as described by Punt (2013). This is particularly relevant for the production of animal products. For example, the cattle herding activity's outputs (milk, beef, manure, draught power and live animals) are not determined by fixed shares (Leontief) as in the standard model, but their production shares can be adjusted depending on relative prices. Thereby the degree of flexibility is governed by the CET parameter. Thirdly, an upward sloping land supply curve is implemented, given the large share of fallow land in Bhutan, which, however, will not provide the same productivity as the land already under cultivation. Further, if demand for land decreases, the return on land decreases as governed by the land supply curve. The supply of land is assumed to be inelastic and the supply function is specified as follows (Orlov and Grethe, 2012):

$$FS_n = shfs_n * WF_n^{elafs_n}$$

Where FS_n is the variable for the supply of land n, $shfs_n$ is a calibrated share parameter, WF_n is the variable for the factor price of land and $elafs_n$ is the land specific supply elasticity parameter.

4.5. Model parameters

For the purpose of comparability, the identical model parameters are implemented for both model setups. For the value added nest L2.2 we apply elasticities from the GTAP database (Hertel *et al.*, 2008). An elasticity of 2 is assumed for activities relying on both private and public capital. In case of activities relying on both agricultural capital accounts (ftiller and finfcapital), a relatively low elasticity of 0.8 is assumed. The elasticity taken for the aggregation of labour (L3.3) equals 1.5 and is based on Hertel (Hertel, 1997). The elasticity of the land-fertilizer aggregate follows Bouët *et al.* (2010), which use an elasticity of 0.4 in the context of developing countries. The elasticity of aggregating chemical fertilizer and organic fertilizer is set as 0.8, which is within the range of estimates of 0.523 and 1.327 that Ali und Parikh (1992) found for non-tractorised and tractorised plots in Pakistan. The elasticity governing the nest

L5.2 only affects the production of spice that use both dryland and orchard, for which an elasticity of 1.2 is assumed. Low elasticities of 0.1 and 0.5 are assumed to hold for the aggregation of field operations at L5.1. The elasticities to aggregate land preparation and plant protection operations at L6.1 and L6.2 are assumed to equal 4 and 0.5.

The Armington elasticities for the aggregation of imports and domestically produced goods are also taken from the GTAP database (Hertel *et al.*, 2008). Income elasticities for households are based on estimates provided by Minten and Dukpa (2010), which estimated an Almost Ideal Demand System (AIDS) for Bhutan using 2007 household data. Frisch parameters for households were set approximating the own price elasticities estimates of Minten and Dukpa (2010).

4.6. Model closures

Our model assumes that Bhutan is a small country, i.e. world market prices are constant. The external balance is flexible and in turn the exchange rate is fixed. This reflects Bhutan's current currency regime of a one-to-one peg of the Bhutanese Ngultrum with the Indian Rupee.[1] The model is investment driven (investment is fixed as a share of final demand) with equiproportionately varying saving rates for households and enterprises. Government consumption and savings are fixed in value terms, and the government account is balanced by changes in the income tax rate. Capital supply is constant and it is assumed to be immobile and thus activity specific. Labour and land are segmented into the previously presented classes, which are perfectly mobile across activities. The numeraire is the consumer price index.

4.7. Labour-migration scenario (lab-mig)

We simulate a factor supply shock scenario abbreviated as "lab-mig", which entails a 5% migration from the physical agricultural workforce (own farm labour and hired agricultural labour) to the unskilled workforce in non-agricultural sectors (i.e. unskilled workers increases by the same number of workers as the agricultural workforce decreases). Within the chosen model setup, this shock inevitably results into an endowment effect, as the average productivity of an unskilled worker is significantly higher than the average productivity of an agricultural worker.

Thus, this simulation rather takes a longer-term perspective, as former agricultural workers obtained the average productivity level of unskilled workers in their new occupations through

[1] India is by far Bhutan's most important trade partner, accounting for more than 78% of imports and 94% of Bhutan's exports in 2012 MoF (2013).

on the job training. The scenario is implemented using both model setups in order to explore how the incorporation of field operations affects model results.

5. Preliminary Results of model setup 2

5.1. Factor markets

The shock primarily affects the balance on the factor markets. With a 5% reduction of workforce in the agricultural sector, this labour category becomes more expensive, causing (implicit) agricultural wages to rise by 10% for own employed labour and 8% for wage labour, respectively. As the rural-urban labour migration causes a significant additional supply of unskilled workers in the industry and service sectors, wages of this labour category drop by 7%. As there is substitution between unskilled and skilled labour, wages of skilled workers are depressed as well (-2%).

The loss of labour in the agricultural sector results in a decrease of overall agricultural production (see below). Therefore, also the demand for cropland is declining. This holds especially for wetland, which is used in labour-intensive paddy production. In total 5.0% of the wetland cropped in the base-situation falls fallow. Dryland and orchards are affected to a lesser extent (-2.4% and -0.1%, respectively). This again causes land rents to drop by up to 15.6% for wetland and by 7.7% and 0.2% for dryland and orchards, respectively.

5.2. Agriculture

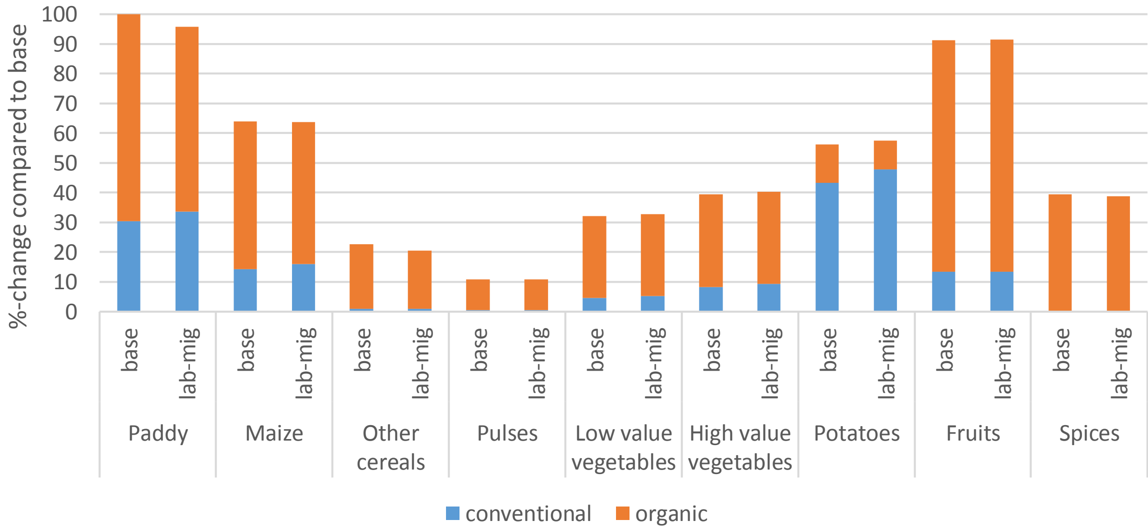

Figure 3 - Output of conventional and organic cropping activities expressed as shares relative to total base paddy production (=100).

The loss of labour and the increasing wages in the agricultural sector provoke that activities and technologies, which are less labour intensive are put at an advantage. More specifically, this means that labour intensive organic cropping activities are reduced in favour for conventional production, which can substitute labour by other inputs to a larger extent. Further, the output of identical crops from organic and conventional activities are considered homogenous, as there is no price premium for organic products in Bhutan. Most considerably is the drop in organic potato-production, which decreases by 24.6%. For this product the share of conventional production is large (compare Figure 2), therefore a 10.2% increase in conventional potato production results in a slight increase of total production. In a similar manner, the negative labour shock is partially balanced in other cropping activities, too (Figure 3).

Especially in the conventional cropping sector additionally the field operations play a larger role, as this sector allows for the substitution between labour intensive organic fertilisation and plant protection with mineral fertilisation and chemical plant protection. With the reduction of agricultural labour, especially labour intensive field operations become more expansive (Figure 4), while prices of less labour intensive operations such as (mineral) fertilisation, chemical plant protection and mechanical land preparation as well as oxen ploughing rise considerably less. This is why where possible labour intensive operations are substituted: In conventional cropping organic fertilization is replaced to some extent by mineral fertilizer application the use of which is increasing by 9.1%. Also chemical plant protection is growing by 10.4%, while organic plant protection declines by 6.2% due to the contraction of the organic production and the substitution in the conventional cropping sector. A similar pattern is observed for soil preparation operations, which can be substituted against each other in organic cropping as well. As less land is cropped, the demand for these activities is reduced, however labour intensive manual ploughing is declining over proportionally with 12.5%, while oxen ploughing is reduced by 4.5% and mechanical ploughing by 0.1% only (Figure 4).

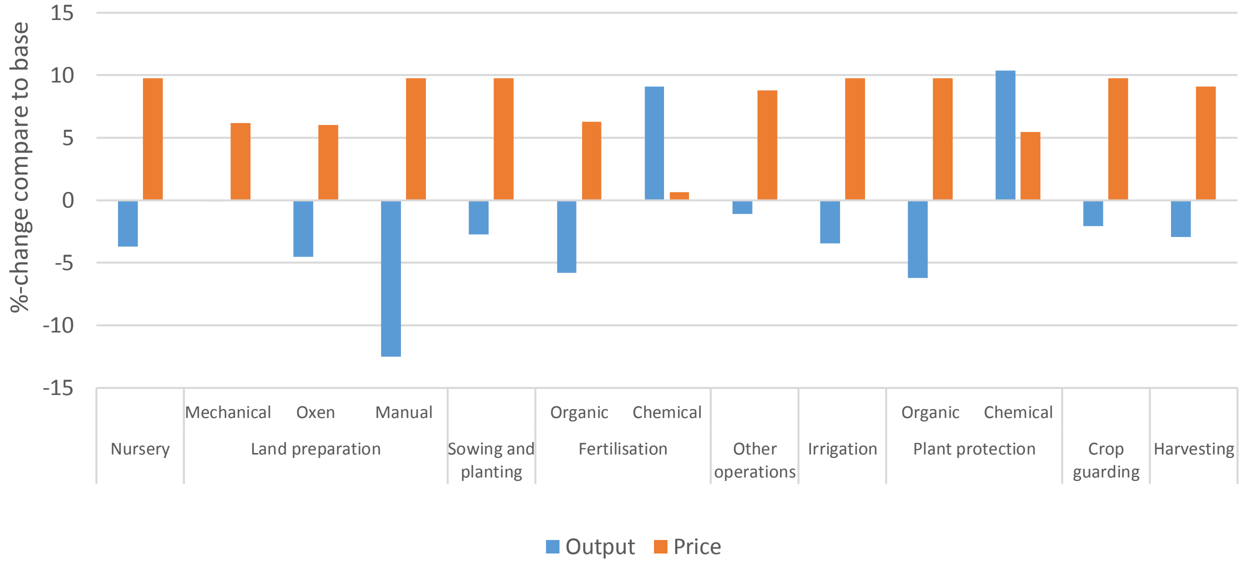

Figure 4 – Changes in demand for and prices of field operations

These production shifts towards a) conventional cropping and b) higher input use (and less labour intensity) causes that total crop production to remain rather balanced, with the biggest output reductions occurring in the production of "other cereals" (-9.2%) and paddy (-4.3%), whereas the production of vegetables and potatoes even increases by around 2% (Figure 3).

Prices of most agricultural products rise, due to the increase in agricultural wages. An exception only constitute vegetables and potatoes whose prices decrease by up to 4.0% (Figure 5).

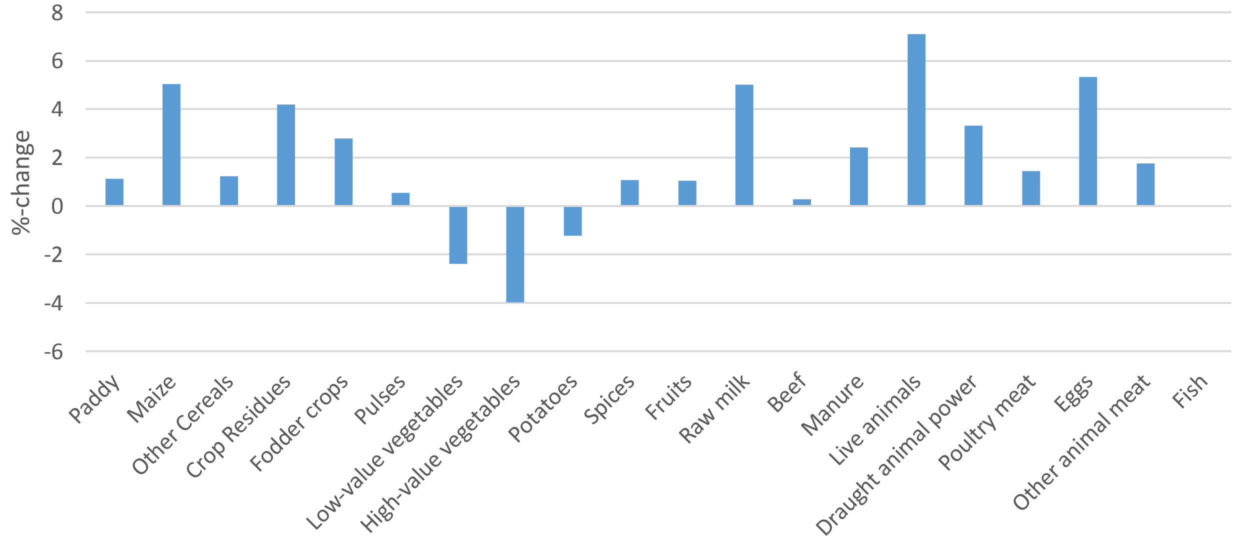

Figure 5 – % Changes in producer prices of agricultural commodities

5.3. Rest of the Economy

The other economic sectors experience an inflow of unskilled labour depressing wages as explained above. Therefore, producer prices of most service commodities and non-food industrial products fall slightly (Figure 6), Thus, these commodities become relatively cheaper (compared to most agricultural and food-products as well as imports) and therefore an increasing demand leads to an expansion of production.

Prices of forestry products rise the most, yet output remains pretty stable (-1.6% for logs and +0.6% for firewood), due to low substitution possibilities on the demand side. The production of most food products decreases as they become more expensive. This is caused by the price increase of the agricultural inputs (compare Figure 5) and increasing imports.

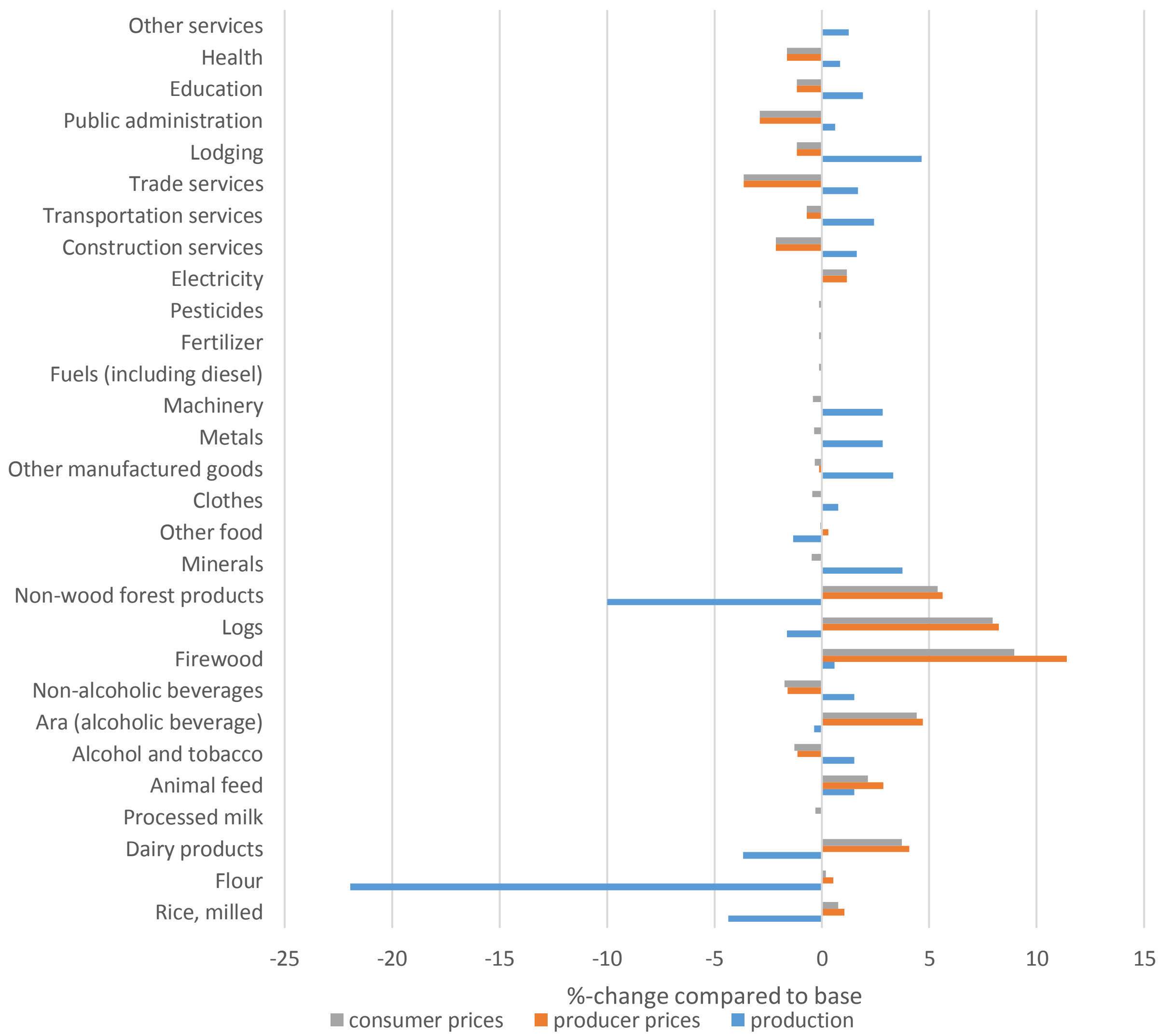

Figure 6 – production and prices of non-agricultural commodities.

5.4. Macroeconomic effects

Due to the labour migration from agriculture to industry and service sectors, average labour productivity is increasing. This results in lower prices of many commodities and an increase of total domestic production and exports by 1.3% and 2.2%, respectively. An increased production together with rising imports (especially industrial products) results in higher tax income to the government. The government budget is balanced by reducing the household tax-rate by 45% equiproportionally over all household groups. This again, in combination with lower prices of many commodities triggers private consumption, which is rising by 0.5%. Finally real GDP grows by 1.1%.

- *Please note: This paper is work in progress and results are preliminary.*

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